238900-2-F

AD-A245 068

Final Report

EVALUATION OF CROP RESIDUE MEASUREMENTS USING LANDSAT THEMATIC MAPPER DATA

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OCTOBER 1991

Submitted To:

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Contract Number: 60-5D21-1-31

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ABSTRACT

The feasibility of using Landsat Thematic Mapper (TM) satellite data to measure crop residue has been investigated. Many previous studies of this type have been done, and they were reviewed as a part of this project. The results of those studies were highly variable, and few consistent general conclusions emerged.

As a result, this project has been structured to examine the feasibility of measuring crop residue from a phenomenological perspective. This approach makes it easier to determine what the fundamental important relationships are. As a result, it is easier to say why a particular approach may or may not work, and what the sources of error are, and how large they are. This approach should lead to the development of robust crop residue estimation procedures, and an understanding of boundary conditions within which the procedures are expected to perform adequately.

Initial analyses were performed on reflectance measurements made on pure samples of soil, residue, and green crop which were collected in the field. These analyses led to the development of a two-band (corresponding to Landsat TM bands 5 and 7) reflectance algorithm which was found to be accurate and robust.

The reflectance-based algorithm was then converted to an algorithm that could be used on actual Landsat TM data. This TM algorithm was implemented on TM data collected on June 7, 1991, and the resulting estimates of percent crop residue in selected fields were compared with field measurements of crop residue in those same fields. The results were highly correlated, and the TM estimates made it possible to categorize most of the fields into their correct crop residue classes.

The results of this project are quite promising. They suggest that there are relatively robust procedures for using Landsat TM data to assist in measuring crop residue. We believe that a semi-operational demonstration of the utility of Landsat TM data for assessing crop residue should now be conducted.

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1.0 INTRODUCTION

Under the conservation provision of the 1985 Food Security Act, and related National Resource Inventory (NRI) program of the U.S. Department of Agriculture/Soil Conservation Service, there is a need for quantifying and monitoring of crop residue cover as part of conservation tillage practices that are being used to control soil erosion and related pollution impacts. Conservation tillage methods retain crop residues after harvesting and planting operations. These residues reduce impacts of rainfall and wind on soil and its consequent erosion.

Voluntary conservation programs are being conducted by the Soil Conservation Service (SCS) which require measuring of residue cover to approximate levels such as, <30%, 30%-50%, and >50% (personal communication, SCS). The current need is to monitor and quantify residue cover during the critical period after crop planting and before crop emergence.

Traditional sample ground measurements and windshield visual survey techniques for monitoring residue cover are inadequate, expensive, time consuming and do not allow 100% monitoring. Remote sensing techniques have the potential of overcoming these limitations.

The objectives of this study are to:

1. determine if TM spectral data acquired after crop planting and before crop emergence can detect and quantify crop residue cover, and if so, to what extent; and

2. to investigate the robustness of relationships between remotely sensed data and crop residue in the presence of variability of background soil types, crop residue types, soil moisture, and conservation tillage practices.

2.0 LITERATURE REVIEW

A brief review of pertinent literature has been done. The emphasis in this review has been to assess current knowledge regarding:

1. factors affecting spectral responses of various components of the soil-residue scene; and

2. some experimental results from various remote sensor studies to detect and quantify residue cover.

The literature that was reviewed for this project is shown in the list of references. Some of the most relevant findings from the literature are summarized here.

2.1 Variations in Spectral Response

The literature review suggests that variation in spectral response depends on a number of factors such as:

a. variability in crop/residue types, standing or littered residue, age of residue, percent residue cover, and dry or wet condition;

b. variability of soil types, soil moisture, random roughness, and tillage/cropping practices; and

c. the characteristics of the remote sensors, the spectral bands used, and the scale of images.

The literature review indicated that the soil background reflectances could be higher or lower than residue reflectances <u>within</u> the same bands, depending on the variety of soil/residue types and states in the scene. The spectral differences <u>within</u> soil types or residue types could be higher than that <u>between</u> soils and residues, within the same bands [Seeley, et al., 1984, Barrett and Lusch, 1991].

As residue weathered with time the spectral reflectances of residue and also the differences of reflectances between residue types tended to get reduced. In cases where residue reflectance was initially greater than background soil, weathered residue tended to have lesser contrast with background soil [Seeley, et al., 1984, Wanjura and Bilbro, 1985].

In cases where residue reflectances were greater than soil background, rainfall increased the spectral contrast. This occurred because soil moisture reduced the soil reflectance more than the residue reflectance [Seeley et al., 1983].

It was found that residue reflectance depended largely on percent residue cover and not significantly on multiple layers of residue, and so reflectance was not related to quantity or density of the residue [Gausman, et al., 1975].

The overall reflectance was affected by shadow of the standing residue, tending to reduce the reflectance. Such variation could also be caused by tillage and cropping practices [Gausman, et al., 1975, 1977].

2.2. Experimental Results

One investigation showed that the use of color infrared (CIR) photography at 1:12,000 scale, using manual interpretation methods in an area containing a variety of soils (dark to light), produced 71% success of classification for four predefined classes (0-19%, 20-29%, 30-50%, and 60-100%). It reported 91% success for only two classes (0-29% and 60-100%) [Whiting, 1986].

Using video CIR imagery from aircraft altitudes (spectral range of visible to near infrared), Barrett found that it was not possible to formulate conclusive rules for identifying high or low residue fields on the imagery [Barrett and Lusch, 1991].

Landsat TM imagery was used to analyze 8900 acres in Seneca County, Ohio, in May 1985 [Logan and Schaal, 1986]. Three analysis techniques were used. Analysis using the Tasseled Cap transformation gave overlapping residue categories that were unacceptable. Analysis using unsupervised classification gave an overall accuracy of 54%. Supervised classification reported 58% accuracy. The major problem was reported as misclassification of residue into the nearest residue category (i.e., a field averaging 20% residue cover was classified into the 0-15% residue category). It was also reported that classification using "overlap categories" of 0-40%, 15-50%, and 40-75% resulted, in an overall accuracy of 77%.

Yet another study in Iowa used Landsat TM data for quantifying residue levels. A ratio of TM bands 5/7 digital values gave maximum correlation with residue levels compared to any other spectral ratios, with r=0.7 (Giglierano and Koch, 1989). The study also indicated that the average ratio value changed with time (from fall to spring crop emergence). It suggests that ratios might be stable over wide areas of the state, although it may be necessary to determine separate regression equations for each major soil/parent material group.

Most of the above experimental results are essentially empirical in nature. As such they do not provide enough information to determine the robustness of the results and of the relationships reported.

3.0 APPROACH

From the review of the literature we conclude that brightness differences alone in one or more bands probably will not provide a stable measure of percent residue cover. This is due to variability in brightness in both the soil and residue types and overlap between brightness values of soil and residue types. Our initial hypothesis, therefore, is that we need to investigate whether there is a chromatic difference between soil types/states and residue types/states, which is also independent of the variability within soil/residue types and states.

Based on the above considerations, the following approach was adopted:

1. Determine spectral reflectance characteristics of the representative soil types/states and residue types/states independent of each other.
2. Parametrically analyze and determine if there are chromatic differences, mutually orthogonal to the "within" spectral variabilities of both the soil types/states and residue types/states.
3. Determine a set of metrics to quantify the differences between 0% residue cover and 100% residue cover based on this analysis, using the most appropriate band(s).
4. Analyze parametrically the robustness of these relationships.
5. Determine the best possible metric and test it on actual Landsat data.

3.1 Description of the Study Area

A test site, the Wolf Creek Watershed, northwest of the city of Adrian in Lenawee County, Michigan, was selected for our investigation. The area consists of level to gently rolling, undulating topography, with soils which included clay loams, silty clay loams, sandy loams, and loamy sand, belonging to the Gray-Brown Podzol Soils [General Soil Map, Lenawee County, Michigan, SCS, USDA Series 1947, No. 10, 1961] of the Great Soil group. An outline map of the area is enclosed as Figure 1.

This site was utilized for several purposes. They include: 1) understanding how crop residue measurements currently are made by SCS personnel; 2) understanding the

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Figure 1. Wolf Creek Watershed, Lenawee County, Michigan

nature of and range of variability of soils, residues, and tillage practices; 3) selection of soil and residue samples for laboratory measurements; and 4) testing of relationships between real field conditions and Landsat TM data.

4.0 DATA COLLECTION

The data collection was organized to meet the objective of the study. Both field data and laboratory data were collected.

4.1 Field Data Collection

Field data were collected on soil and residue types representative of the area on June 7, 1991. Table 1 lists the characteristics of the fields on which residue cover measurements were made. The fields had corn, soybean, or wheat residues, with soils with a range of conditions. Percent residue cover was measured by the Line-Transect Method [Shelton, et al.], as that method has been found to be relatively accurate [Laflon, et al., 1981]. Data collection and residue measurement was assisted by SCS field office personnel and the SCS Contract Monitor. Representative samples of residue types and soil types were collected for later laboratory measurements. Photographs (35mm) of samples and sites were taken for future evaluation. A few Spectrofax field reflectance measurements were made. Two representative photographs of the residue types (corn, and wheat) are shown in Figure 2. The photographs also show the use of the line-transect method in progress.

4.2 Laboratory Measurements

Reflectance measurements were made on pure soil and residue samples collected from the field, both in dry conditions and wet conditions. The reflectance measurements were made on a Beckman Spectro-photometer covering the spectral range from 0.4 μm to 2.5 μm.

Figures 3 and 4 show a sample of the range of variability of spectral reflectances of residues and soils over the spectral regions covered by the Landsat TM sensor.

Mean reflectances in TM bands were extracted from Beckman reflectance curves by averaging a number of values over each spectral band range of the TM sensor. These data were used to carry out parametric analysis for detecting spectral differences between residue types and soil types.

Table 1. Field Data Collected on June 7, 1991, in Wolf Creek Watershed

FIELD #	SOIL TYPE COLOR	TILLAGE PLANTING DATE	RESIDUE TYPE (transect estimated percent cover) subjective visual est. (%)	CROP TYPE; plant row spacing CROP HEIGHT (% crop cover)
11	Clay Loam 10 YR 33	No till 2 weeks prior	Corn (68%) 70, 80%	Soybean; 7 1/2" 3"-4" (6%)
12	Clay Loam 10 YR 42	Spring chisel plowed May 30	Corn (27%) 15%	Soybean; 30" 1" (0%)
13	Clay Loam 10 YR 63	Conventional tillage Not planted	Bare (0%) 0%	None (0%)
14	Clay Loam 10 YR 63	No till NA	Corn (69.5%) 75%	Soybean; 7 1/2" (0%)
15	NA 10 YR 73	Mole-bored till NA	Grass (1%) 2%	Corn; 30" 10-12" (3%)
16	NA 2.5 Y 67	No till NA	Corn (57.5%) 65,70,72%	Soybean; 7 1/2" 3-4" (2%), weed=1%
17	NA NA	NA NA	Wheat (NA) 5%	Soybean; 7 1/2" 1" (0%)
18	NA 10 YR 73	Chisel plowed NA	Corn (36%) 50%	Soybean; 7 1/2" (0%)
19	NA NA	Chisel plowed NA	Corn (30%) 30%	None Weed=4%
20	NA 10 YR 73	Chisel plowed 2 weeks prior	Corn (20%) 22%	Corn; 30" 2-3" (6%)

Table 1. Field Data Collected on June 7, 1991, in Wolf Creek Watershed (Continued)

FIELD #	SOIL TYPE / COLOR	TILLAGE / PLANTING DATE	RESIDUE TYPE (transect estimated percent cover) / subjective visual est. (%)	CROP TYPE; plant row spacing / CROP HEIGHT (% crop cover)
21	NA / 10 YR 63	No till / NA	Wheat (70.5%) / 70%	Soybean; 30" / 4" (7%)
22	NA / 2.5 Y 62	Clean till / NA	Soybean (NA) / 1-2%	None / (0%)
23	NA / 10 YR 63	NA / NA	Corn (18%) / NA	None / (0%)
24	NA / 10 YR 63	No till / Just planted	Corn (68%) / NA	Soybean; 30" / (0%), weed=2%
25	NA / NA	Recently chiseled / Plowed - 4 hours	Soybean/weed (NA) / 5%	None / (0%)
26	NA / 10 YR 63	No till / NA	Corn (65%) / NA	Soybean; 7 1/2" / 4" (7%)
27	NA / 10 YR 63	No till / NA	Wheat (68%) / 55%	Soybean; 7 1/2" / 3-4" (1%)
28	NA / 10 YR 63	Chisel plowed / NA	Corn (20%) / NA	Soybean; 7 1/2" / 3" (3%)
29	NA / NA	NA / NA	Corn (20%) / 30%	Soybean; 7 1/2" / (0%)
30	NA / 10 YR 63	Mole-bored, plowed / NA	Bare (0%) / 0%	Corn; 30" / 6" (9%)
31	NA / 10 YR 73	Chisel Plowed / NA	Soybean (6%) / NA	Soybean; 30" / 2" (4%)

Notes: NA = Not Available

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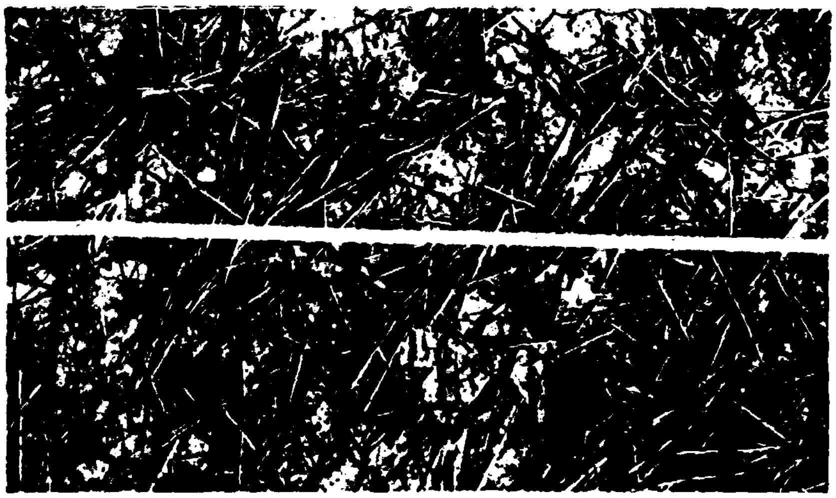
(a) Corn Residue—68 Percent Cover in Field #11



(b) Wheat Residue—68 Percent Cover in Field #27

Figure 2. Vertical Photographs of Selected Crop Residues

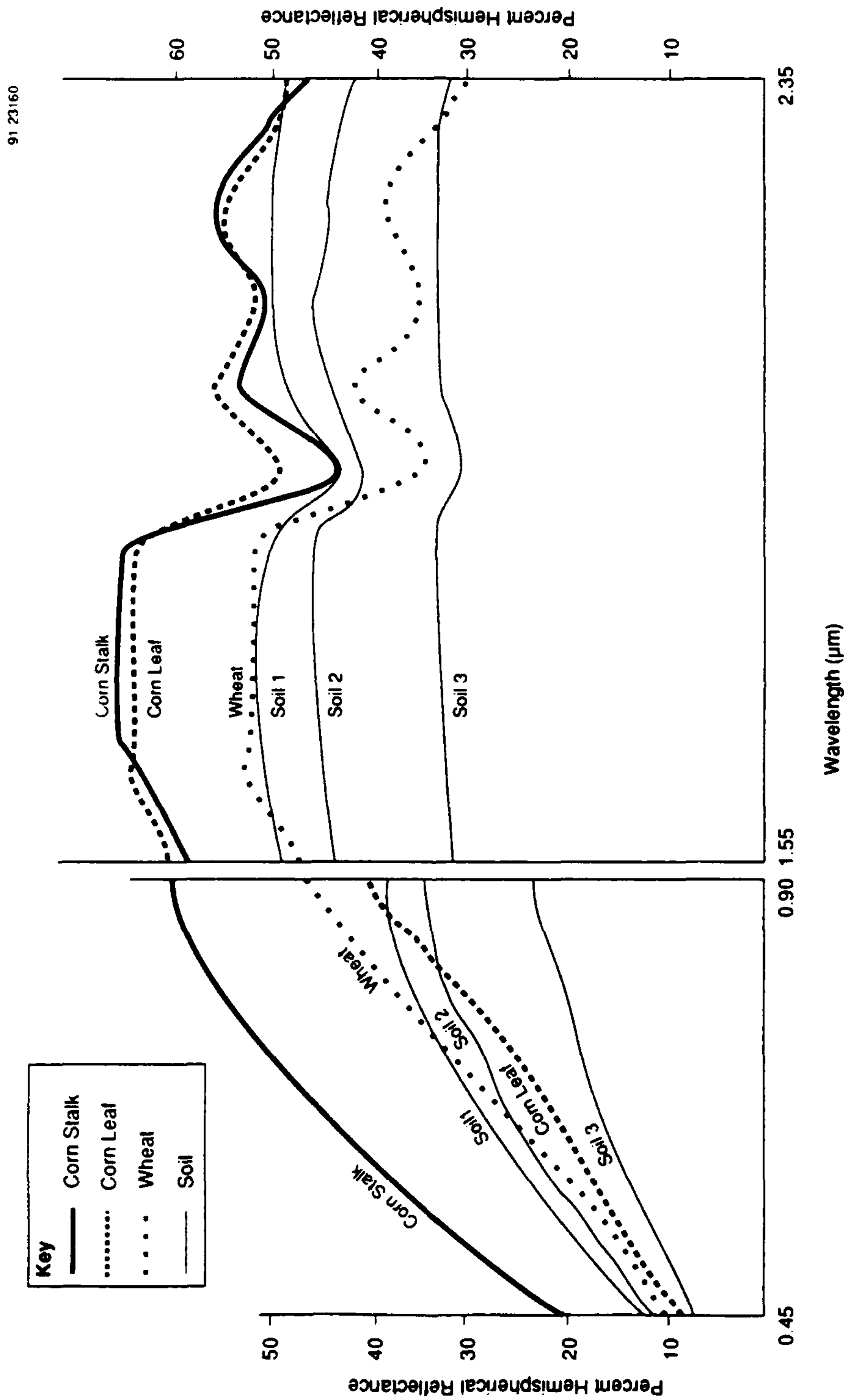


Figure 3. Selected Reflectances of Dry Soil and Residue Samples

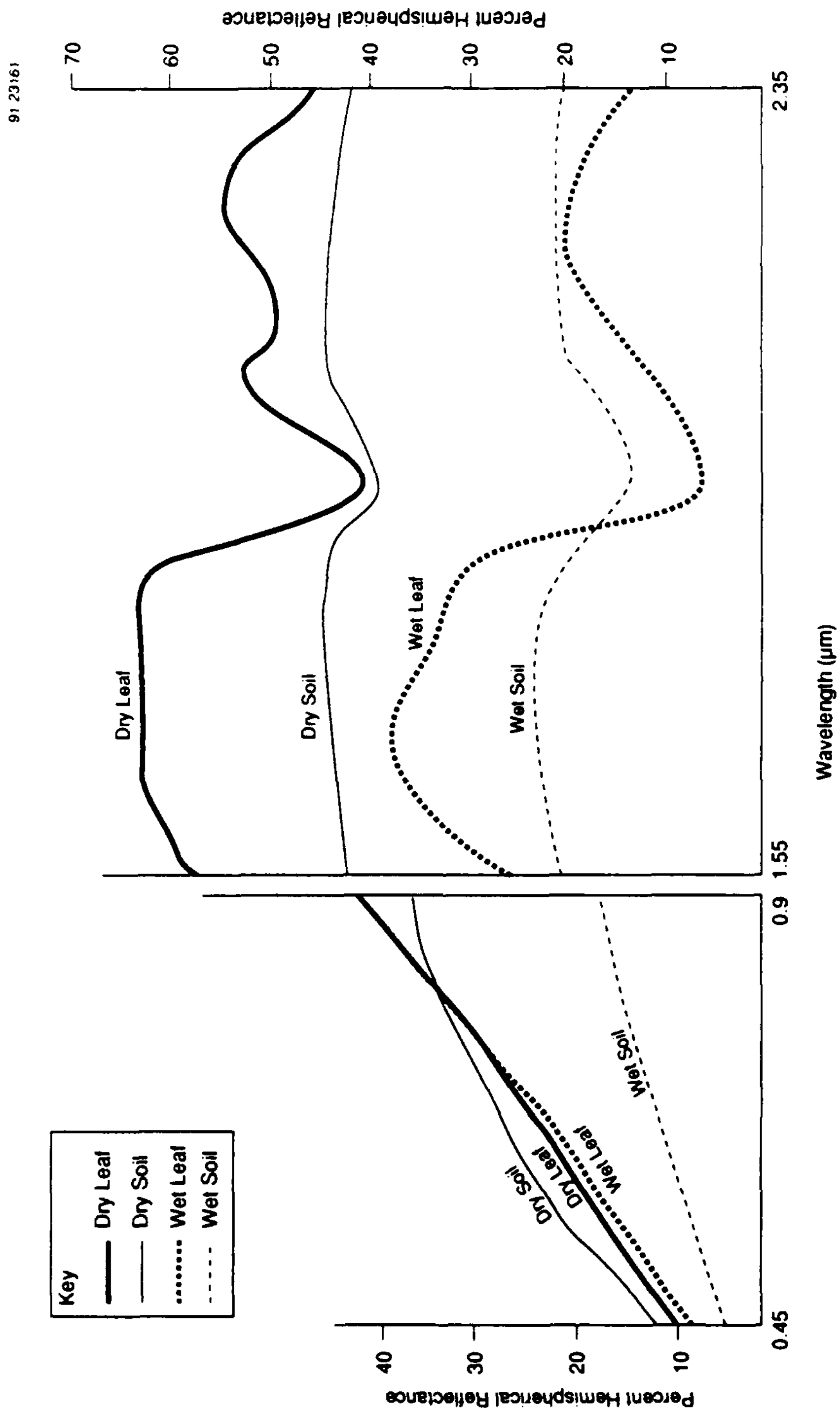


Figure 4. Selected Reflectances of Dry and Wet Soil and Residue Samples

4.3 Moisture-Effect Measurements

Soil and residue samples were photographed when dry and rephotographed after wetting, and again after allowing the samples to be air dried. This allowed us to determine the relative rate of drying of soils and residues after a rainfall so that representative laboratory reflectance measurements could be made to simulate possible TM data collection conditions after a rainfall.

Figure 5 shows the dry soil types and dry residue types, and Figure 6 shows the same samples after wetting and allowing to air dry in the sun for 20 minutes. The figures display the range of soil types, and the range of residue types (stalk and leaf). Figure 6 shows that soils generally take longer to dry, and that both soil types and residue types dry at different rates at the surface.

These figures also show that residue can be brighter or darker than the soil, depending upon the type and state of the soil and the residue. This also shows that variation in brightness within a class of materials (e.g., soil) may be as great or greater than the brightness difference between a particular soil and residue type.

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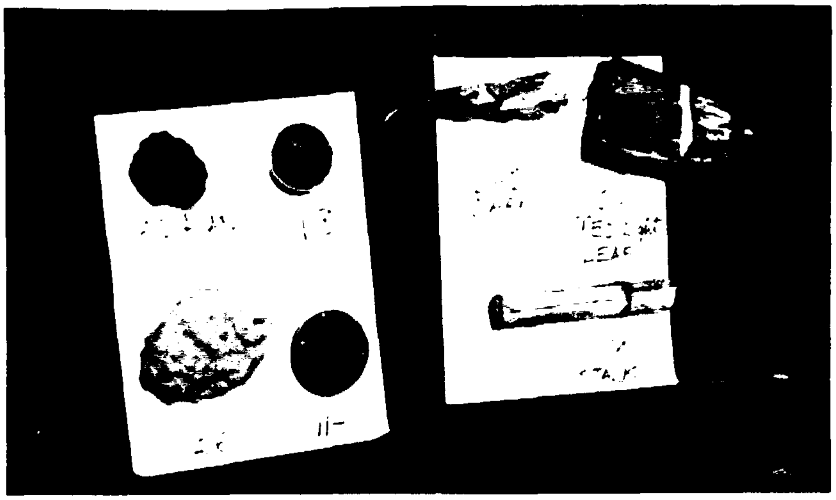

Figure 5. Selected Dry Soil and Residue Samples

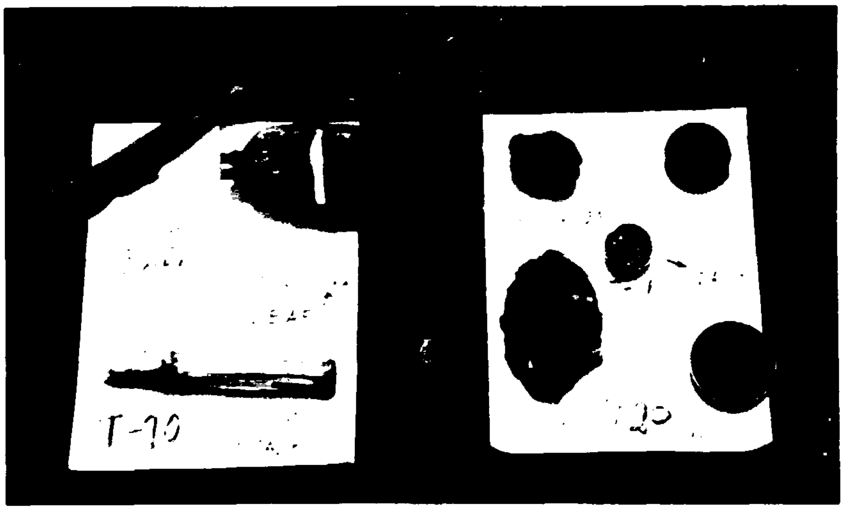

Figure 6. Selected Soil and Residue Samples After Wetting and Air Drying for 20 Minutes

5.0 REFLECTANCE DATA ANALYSIS

The reflectance data set consisted of simulated (from Beckman laboratory measurements) reflectance values for the six reflective TM bands for dry and wet soil and residue. The six bands of TM reflectance values were subjected to principal components analysis. This analysis showed that the vast majority of the overall variability in reflectance values within both groups (soil and residue) was in the overall brightness of all of the bands (i.e., a positively weighted sum of all of the bands). Unfortunately, much of the variability between groups was also found to be in the overall brightness. However, significant between group variability was also found to exist in other orthogonal dimensions, and this variability furnishes some hope for separation of the two groups. The subsequent analyses were designed to explore and exploit this possibility.

Stepwise discriminant analysis for separation of soil and residue was implemented. It showed that TM bands 5 and 7 were important bands for separation of soil and residue, and that when they were included, other bands were not statistically significant in the separation. All other 2-band combinations were also analyzed, and TM bands 5 and 7 were found to be the most useful 2 bands, with little additional useful information regarding crop residue cover afforded by the addition of other bands. As a result, subsequent analyses concentrated on exploring the utility of these two TM bands to separate soil from residue, and to produce a metric for estimating percent residue cover.

Spectral plots were made of the soil and residue samples in TM bands 5 and 7. The plot is shown in Figure 7. Examination of the plot clearly shows that in spite of the large variability in reflectances of soil and residue types, there is a chromatic difference orthogonal to the spectral variabilities of the soil types and residue types. It is this chromatic difference that can provide a basis for quantifying percentage residue cover, as this difference represents the range (from 0 to 100%) of crop residue.

A parametric analysis was implemented in order to assess the effect of variability of soil, residue, and other factors on the robustness and performance of an algorithm for assessing percent crop residue.

A variety of equations for estimating percentage crop residue were developed using regression analysis. These

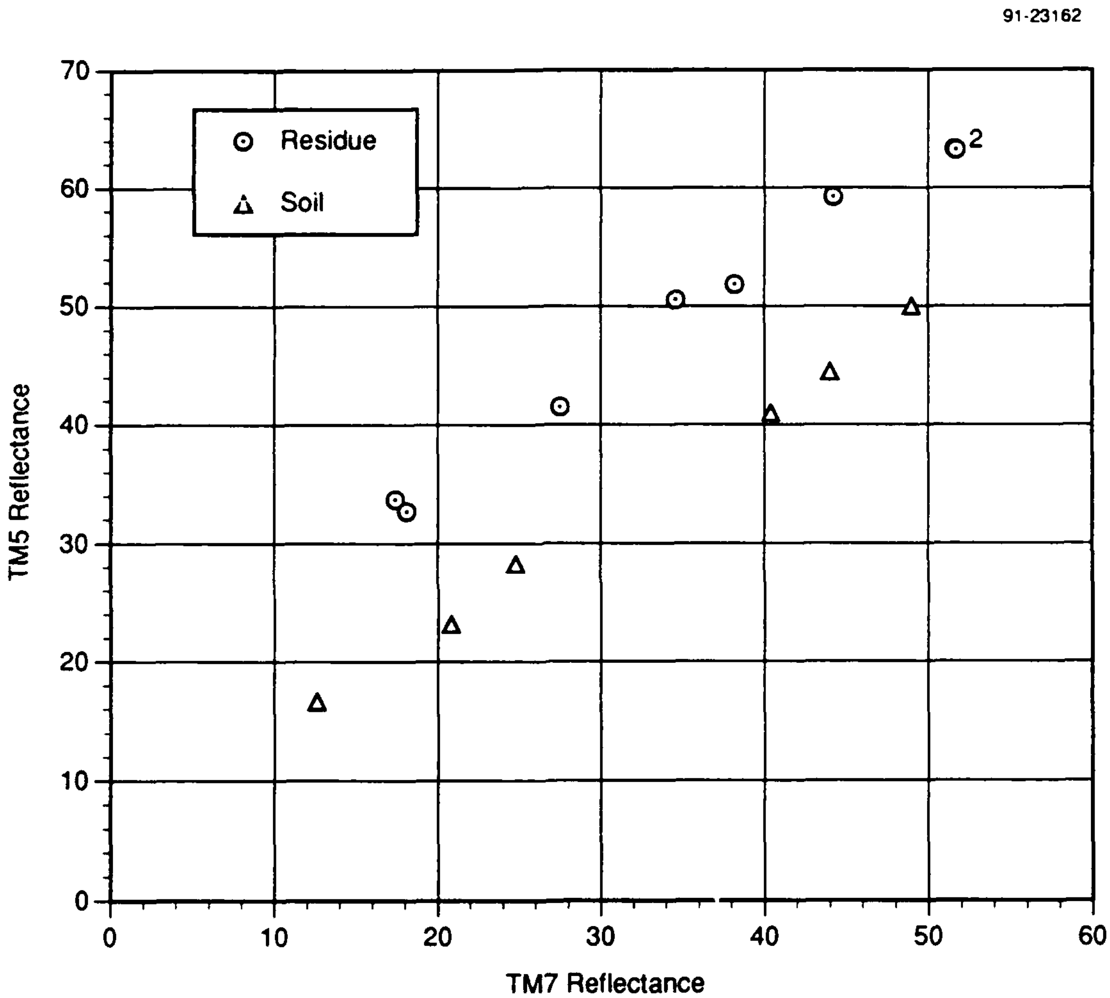

Figure 7. Reflectance Data in TM Bands 5 and 7 for Selected Samples

were developed from the reflectance measurements of pure soil (0% crop residue) and pure crop residue (100% crop residue), for TM bands 5 and 7. Equations were generated for various combinations of soil types and states and crop residue types and states. Each equation was examined to see how the equations varied (e.g., the coefficients of TM5 and TM7), and how the performance of the equation (e.g., the Mean Square Error, MSE) varied. In addition, selected equations developed on one set of soil types/states and residue types/states were applied to a different set of soils and residues to see how robust the relationships were for varying soil/residue conditions.

For example, the equation for predicting percent crop residue based on just dry corn residue and dry soils was:

$$\text{Crop Residue (\%)} = 9.47\rho_{TM5} - 9.93\rho_{TM7} + 13.75$$

The mean square error was 1.75% crop residue.

When this same equation was used to predict percent residue for dry soil and both dry corn and dry wheat residues, the MSE of prediction jumped to 27.3% crop residue. When this equation was used to predict crop residue for both wet and dry soil as well as dry corn and wheat residue, the MSE increased to 42.3%.

This parametric analysis indicated that using a crop residue prediction equation based on too narrow a range of samples would not be robust in being able to accurately predict crop residue if soil or crop residue type or condition changed.

We then constructed a crop residue prediction equation based on all of the soil and residue types and states we thought might reasonably occur in an area like Lenawee County. These include several soil types in both wet and dry states, plus corn and wheat residue in dry and wet states.

The resulting crop residue prediction equation was:

$$\text{Crop Residue (\%)} = 7.8836\rho_{TM5} - 7.1148\rho_{TM7} - 39.155$$

This equation had less good predictive capability than equations based on and applied to a subset of data points, but it performed reasonably well for all soil and residue types and states, with a MSE of 8.4% and a worst error of 13%. Thus, we believe that this equation should be a relatively robust crop residue prediction equation over a considerable range of conditions, using only the two best TM bands.

The ratio of TM reflectances in bands 5/7 was also computed and regressed with percentage cover. This gave a MSE of 39%. Thus the ratio of TM bands 5/7 reflectances was not a good predictor of percent cover. This is evident from the scatter of reflectances in bands 5 and 7 (Figure 7). Lines drawn through the soil and residue variability respectively are nearly parallel and do not pass through the origin. Therefore the ratio of reflectance values will not give invariant values for soil and crop groups, and in fact may increase the variability within soil and residue groups.

There are many possible additional sources of error in predicting crop residues. Among these are presence of green vegetation cover, shadow, and variable irradiance on terrain with variable slope and aspect. Some of these sources were cursorily investigated.

For example, the presence of green vegetation was crudely simulated by using the reflectance of Beckman-measured green corn and simulating the reflectance of a field with 10% green vegetation (and no residue). The crop residue prediction equation was then used on this simulated field and indicated that the 10% green vegetation made the bare field appear as though it had about 5% crop residue. Thus, the effect of green vegetation covering soil is similar to that of dead residue, but not as great.

The effect of slope was cursorily investigated by altering the reflectance by an amount that would simulate a 10% slope. This produced an error of about 6% in the estimation of crop residue.

6.0 LANDSAT TM PROCESSING AND ANALYSIS

The reflectance-based algorithm for predicting crop residue was converted directly to an algorithm for predicting crop residue with Landsat TM data. The transformation was based on the calibration of Landsat digital values to radiance, and the calculation of equivalent reflectance under specific atmospheric conditions (transmittance and path radiance), and illumination conditions appropriate to the TM data acquisition. Only the multiplicative coefficients were transformed, since only they have a relationship between reflectance and digital values. The resulting discriminant line in TM space was (after appropriate scaling).

Crop Residue (Relative %) = 2.627 * TM5 - 4.189 * TM7

An offset term was added to prevent clipping of data at 0. This meant that the Landsat algorithm was scaled to units of relative percent residue cover, but with an arbitrary offset.

The Landsat TM digital values were then converted to relative crop residue estimates using this equation. The resulting Landsat estimates of percent crop residue were then compiled from pixels representative of each field which was observed by the ground party on the date of the overpass. The Landsat estimates of relative percent crop residue were then compared to field estimates of crop residue (from Table 1). The results are shown in Figure 8.

A regression was performed between field estimates of percent cover and the Landsat predictions of relative percent cover. The resulting equation was:

Field estimate = 1.08 * Landsat estimate - 87.0.

The correlation between the two estimates was 0.914, so that 83.5% of the variance in crop residue measurements made in the field was accounted for by the Landsat estimates. The MSE of the estimate of field measurements was 11.4 percent residue. Accurate estimation of actual percent residue values would probably require calibration of the Landsat estimates to a few field measurements.

A regression based on the actual TM digital values produced a MSE of the estimate of 9.87 percent residue; only

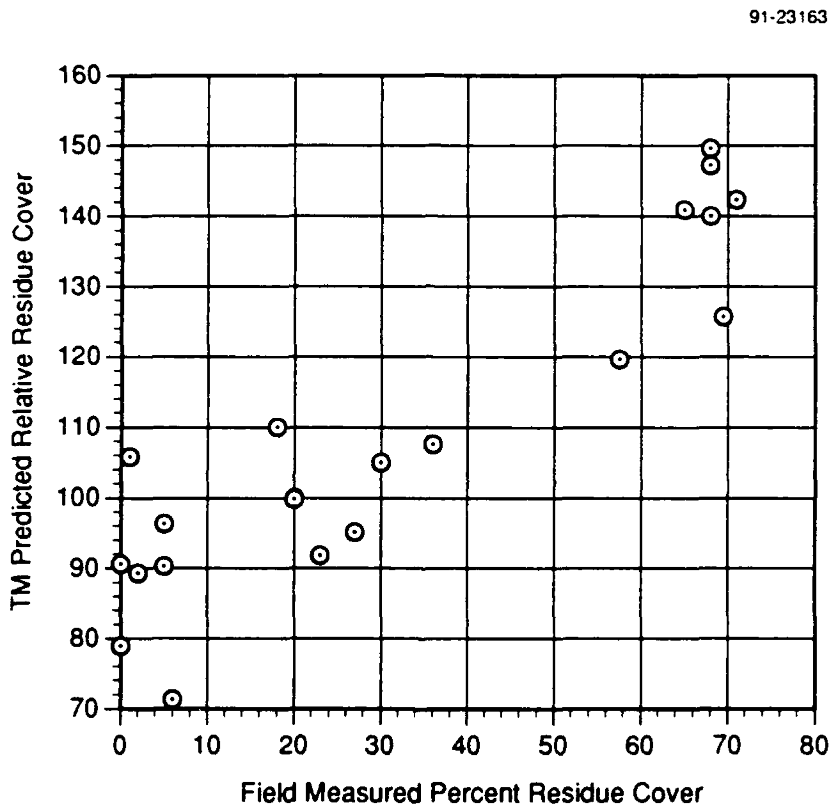

Figure 8. Comparison Between Field Measured Percent Residue Cover and Corresponding TM Predicted Relative Residue Cover

slightly lower than the reflectance-based algorithm. The correlation also improved only slightly, to 0.941.

When correctly calibrated, the Landsat estimates of crop residue could be used to categorize fields into crop residue categories relevant to the SCS (e.g., 0-29%, 30-49%, ≥ 50%). By level slicing the Landsat estimate of crop residue, all but two of the 21 fields could be correctly placed in their appropriate residue category.

7.0 DISCUSSION

A number of issues relevant to measuring crop residue became evident in the course of this project. Several of those are discussed here.

7.1 Sources of Error and Variability in Performance.

The characteristics of the fields visited by the ground observation team were reviewed in order to assess the effects of these characteristics on crop residue estimation. The sample of fields and associated field characteristics was not large enough to make definitive conclusions, but some preliminary results are worth noting.

There was no obvious evidence that the type of crop residue or the soil type had a significant effect on the ability to make crop residue estimates. By this, we mean that there was no consistent bias or error due to these differential factors. This result is consistent with the results from analysis of the reflectance data set. However, the reflectance analyses also suggest that there may be some kinds of soils not observed in the Lenawee county site (e.g., highly organic soils), which could be major sources of error, and may require a different approach or modified algorithm. In addition, the reflectance analyses indicated that different amounts of weathering and decomposition of crop residue could have a significant effect. In general, the ability to accurately estimate crop residue appears to decrease as the residue weathers, because it looks more like soil. The crop residue estimation equation implemented on the TM data would produce a lower estimate of crop residue cover (a negative bias) if the residue were more weathered than the "average" Lenawee crop residue.

With respect to tillage practices, there was not enough variability for us to determine whether this has an effect on estimation of crop residue. More analysis of this effect seems warranted, but we do not anticipate it being a significant source of error.

The effect of the current year's crop on crop residue estimation was not large. However, this was probably because none of the fields visited had a high green crop cover at the time of the Landsat data acquisition. In general, based on the reflectance analyses that were performed, we expect green vegetation to have a positive bias on crop residue estimation. Since some SCS field personnel considered green weeds to be "crop residue", this potential "bias" may actually be appropriate in some cases.

The effect of variable atmospheric conditions was also cursorily investigated by simulating TM algorithms with two types of atmospheres, clear (23 km visibility) and hazy (5 km visibility). Atmospheric effects were apparent in the algorithm, but were less of a source of error in crop residue estimation than would have occurred in an algorithm dependent on the brightness of a single band.

In a particular data set, information in spectral bands other than TM 5 and TM 7 may prove to have utility in estimating the amount of crop residue. However, the phenomenological reasons for this are not obvious, and we do not expect relationships using other bands to be robust. In fact, the utility and relationships in including TM 4 with TM 5 and TM 7 for residue estimation were found to be quite different for reflectance data and actual TM data. Therefore, based on the evidence currently available to us, we recommend using an algorithm based only on TM 5 and TM 7.

In comparing the utility of field measurements of crop residue with remote sensing estimates for a particular field, differences in the characteristics of these measurements should be appreciated. Objective field measurements can be made rather accurately, but they can not routinely be made throughout each and every field. Even field measurements can be inaccurate, however, if they are made without care, and different field personnel can produce different estimates.

Remote sensing estimates may be less "accurate," but they can be routinely made throughout each and every field, and hence be more "precise." The result is that field measurements will have more sampling error ("imprecision"), whereas remote sensing measurements may have more "bias." An optimal estimation approach may require both kinds of measurements.

7.2 Operational Implementation Strategies

A number of issues need to be examined in order to assess whether Landsat TM data will be of operational utility in estimating crop residues. These issues include: (1) the time interval (window) during which the approach is possible and useful; (2) how quickly the TM data that are collected can be obtained from EOSAT for use by field workers; (3) procedures for optimal use of the TM data by field workers, and methods to do so; (4) the degree to which it is necessary to calibrate a TM crop residue estimation algorithm for a particular set of conditions, and efficient procedures for doing so; and (5) the cost-effectiveness of the use of TM data as an aid to monitoring crop residue.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The results of this project are very promising. They suggest that there are relatively robust procedures for using Landsat TM data to assist in measuring crop residues.

We recommend that a semi-operational demonstration of the utility of Landsat TM data for assessing crop residue be conducted. This semi-operational demonstration would serve to test the preliminary conclusions reached in the present study, and would assess the operational feasibility and cost-effectiveness of using TM data in ongoing SCS monitoring activities.

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